EXPERIMENT A5: TYPES OF REACTIONS

Learning Outcomes

Upon completion of this lab, the student will be able to:

1) Examine different types of chemical reactions.
2) Express chemical equations in molecular, ionic, and net-ionic forms.
3) Predict solubility rules for some ionic substances in water

Introduction

There are several different types of chemical reactions such as: combustion, precipitation, acid-base, decomposition, oxidation-reduction etc. Some evidences for the occurrence of a chemical reaction include one or more of the following:

- Formation of a precipitate
- Color change
- Gas formation
- Temperature change

Three different types of chemical reactions will be considered in this experiment: 1) precipitation 2) acid-base and 3) gas formation. For each type of reaction, it is important to learn to write the molecular equation, total ionic equation, and net ionic equation. The observations from these reactions will enable the development of the solubility rules for simple ionic substances.

Precipitation Reactions

When aqueous solutions of two inorganic salts are combined, a type of reaction referred to as *metathesis reaction* takes place. These reactions are also referred to as double replacement or double displacement reactions. In this reaction the cation of the first solution combines with the anion of the second solution and vice versa. For instance, consider the combination of aqueous solutions of sodium chloride and silver nitrate. The molecular equation for the reaction is given below:

$$NaCl_{(aq)} + AgNO_{3(aq)} \rightarrow NaNO_{3(aq)} + AgCl_{(s)} \qquad \textbf{Equation 1}$$

In the above example, note that when Ag^+ from the silver nitrate solution combines with the Cl^- from the sodium chloride solution, a precipitate of AgCl is formed. Hence, this metathesis reaction is an example of a precipitation reaction.

The fact that AgCl will be a precipitate in this reaction can be predicted by using the "Solubility Rules". The reactions studied in this experiment will help determine some of these solubility rules.

Equation 1 shown above is referred to as the "*molecular equation*", an equation that shows all the reacting substances and products as molecules. But, soluble ionic compounds are strong electrolytes, and strong electrolytes completely dissociate into their component ions in an aqueous medium. So the more appropriate form of writing the chemical reaction would be as follows:

$Na^{+}_{(aq)} + Cl^{-}_{(aq)} + Ag^{+}_{(aq)} + NO_3^{-}{}_{(aq)} \rightarrow Na^{+}_{(aq)} + NO_3^{-}{}_{(aq)} + AgCl_{(s)}$ **Equation 2**

Equation 2 is the "*total ionic equation*" for the reaction depicted in equation 1. Note than in this equation, the precipitate is written as an intact substance as it does not dissociate into ions.

A close examination of equation 2 also reveals that $Na^{+}_{(aq)}$ and $NO_3^{-}{}_{(aq)}$ are found both on the reactant side as well as the product side. These ions are not transformed during the chemical process and are referred to as the "*spectator ions*" and may be cancelled from both sides of the equation. Equation 2 is then reduced to the following:

$Ag^{+}_{(aq)} + Cl^{-}_{(aq)} \rightarrow AgCl_{(s)}$ **Equation 3**

Equation 3 is referred to as the "*net ionic equation*".

Combinations of inorganic salts that do not yield a precipitate are essentially ones where no reaction has taken place.

Acid-Base Reactions

The reaction between Arrhenius acids and bases may also be considered as a metathesis reaction. Consider the reaction between aqueous solutions of hydrochloric acid and sodium hydroxide. The molecular (equation 4), total ionic (equation 5), and net ionic equations (equation 6) for this reaction are shown below. (Note that HOH is the same as H_2O and has been written in this form to illustrate the double replacement reaction)

$HCl_{(aq)} + NaOH_{(aq)} \rightarrow NaCl_{(aq)} + HOH_{(l)}$ **Equation 4**

$H^{+}_{(aq)} + Cl^{-}_{(aq)} + Na^{+}_{(aq)} + OH^{-}_{(aq)} \rightarrow Na^{+}_{(aq)} + Cl^{-}_{(aq)} + H_2O_{(l)}$ **Equation 5**

$H^{+}_{(aq)} + OH^{-}_{(aq)} \rightarrow H_2O_{(l)}$ **Equation 6**

While sodium hydroxide is a soluble substance, not all ionic substances with hydroxide as the anion are soluble. The reaction of an aqueous acid with a solid hydroxide can cause the insoluble hydroxide to be dissolved. Such an example is shown in the reaction between aqueous hydrochloric acid and solid zinc hydroxide;

the molecular (equation 7), total ionic (equation 8), and net ionic equations (equation 9) for this reaction are shown below.

$2HCl_{(aq)} + Zn(OH)_{2(s)} \rightarrow ZnCl_{2(aq)} + 2HOH_{(l)}$ **Equation 7**

$2H^+_{(aq)} + 2Cl^-_{(aq)} + Zn(OH)_{2(s)} \rightarrow Zn^{2+}_{(aq)} + 2Cl^-_{(aq)} + 2H_2O_{(l)}$ **Equation 8**

$2H^+_{(aq)} + Zn(OH)_{2(s)} \rightarrow Zn^{2+}_{(aq)} + 2H_2O_{(l)}$ **Equation 9**

<u>Gas Formation Reactions</u>

There are two types of gas formation reactions that will be encountered in this experiment: a) acids reacting with carbonates or hydrogen carbonates and b) certain metals reacting with acids or water.

a. Acids + carbonates/hydrogen carbonates

These reactions may also be thought of as a metathesis reaction. For instance, consider the reaction between aqueous hydrochloric acid and solid calcium carbonate:

$2HCl_{(aq)} + CaCO_{3(s)} \rightarrow CaCl_{2(aq)} + H_2CO_{3(aq)}$ **Equation 10**

The carbonic acid, H_2CO_3, in fact is found as H_2O and CO_2, so the more appropriate equation would be:

$2HCl_{(aq)} + CaCO_{3(s)} \rightarrow CaCl_{2(aq)} + H_2O_{(l)} + CO_{2(g)}$ **Equation 11**

The total ionic (equation 12) and net ionic equations (equation 13) for the above molecular equation are given below.

$2H^+_{(aq)} + 2Cl^-_{(aq)} + CaCO_{3(s)} \rightarrow Ca^{2+}_{(aq)} + 2Cl^-_{(aq)} + H_2O_{(l)} + CO_{2(g)}$ **Equation 12**

$2H^+_{(aq)} + CaCO_{3(s)} \rightarrow Ca^{2+}_{(aq)} + H_2O_{(l)} + CO_{2(g)}$ **Equation 13**

The reaction between acids and metal hydrogen carbonates is identical to that shown above between acids and metal carbonates.

b. Metals + acid/water

The reaction between metals and acid/water belongs to the category of "Single Replacement Reactions". These reactions may also be categorized as "Oxidation-Reduction Reactions". The details of these reactions will be discussed later on in General Chemistry.

In these reactions, the metal displaces “H” from the acid; this results in the formation of hydrogen gas. For instance:

$Metal_{(s)} + HCl_{(aq)} \rightarrow Metal\ chloride_{(aq)} + H_{2(g)}$ **Equation 14**

In these reactions, the metal is essentially replacing “H” in the acid. But, not all metals are able to replace “H” in the acid. In order for a metal to be able to replace “H” from the acid, the metal needs to be “*more active*” than “H”.

The “activity” of a metal is given by the “activity series”. A partial activity series is given below:

Activity Series: Li > Na > Mg > Zn > Co > Ni > (H) > Cu > Ag > Au

As mentioned above, a more through discussion of how the activity series is developed will be discussed later on in General Chemistry.

Based on the activity series, metals such as sodium, zinc etc., will be able to displace “H” from acids, whereas metals such as Cu, Ag etc., will not react with acids.

$Zn_{(s)} + 2HCl_{(aq)} \rightarrow ZnCl_{2(aq)} + H_{2(g)}$ **Equation 15**

$Ag_{(s)} + HCl_{(aq)} \rightarrow$ No Reaction **Equation 16**

Experimental Design

Two sets of inorganic salts will be provided. Each reagent from one set will be combined with each reagent in the second set. The various reactions will be conducted in spot plates. For each set of reactions, place appropriate number of drops of the reagents in one of the wells of the spot plate and carefully observe the chemical reaction (if any). Please note that the indicators of a chemical reaction are: formation of a precipitate, color change, gas formation, and temperature change.

Part 1: aqueous solutions of inorganic salt 1 + inorganic salt 2
Part 2: aqueous inorganic salt + aqueous NH_3
Part 3: aqueous inorganic salt + aqueous NH_3
Part 4: solid inorganic salt or metal + water or aqueous HCl

Reagents and Supplies

0.9 M solutions of $Ba(NO_3)_2$, $Ca(NO_3)_2$, $Mg(NO_3)_2$, $Co(NO_3)_2$, $Cu(NO_3)_2$, $Al(NO_3)_3$, NH_4NO_3, Na_2CO_3, Na_2SO_4, NaOH, and NaCl, 1 M NH_4OH, 6 M HCl, solid- $CaCO_3$, Zn, $Mg(OH)_2$

(See posted Material Safety Data Sheets)

Spot plates

Procedure

PART 1: AQUEOUS SOLUTIONS OF INORGANIC SALT 1 + INORGANIC SALT 2

1. The solutions provided for inorganic salt 1 are: 0.9 M solutions of $Ba(NO_3)_2$, $Ca(NO_3)_2$, $Mg(NO_3)_2$, $Co(NO_3)_2$, $Cu(NO_3)_2$, $Al(NO_3)_3$, NH_4NO_3.

2. The solutions provided for inorganic salt 2 are: 0.9 M solutions of Na_2CO_3, Na_2SO_4, NaOH, and NaCl.

3. Obtain a clean spot plate. Place four drops of $Ba(NO_3)_2$ in four wells of the spot plate.

4. Add 2-3 drops of each of inorganic salt 2 to the wells containing $Ba(NO_3)_2$. Mix the contents of the well with a clean stirring rod.

5. Record your observations.

6. Repeat steps 3-5 with each of the other reagents from the inorganic salt 1 list.

7. Empty the contents of the spot plate into a large waste beaker and rinse the plate with water.

PART 2: AQUEOUS INORGANIC SALT + AQUEOUS NH_3

1. Obtain a clean spot plate. Place four drops each of 0.9 M $Ba(NO_3)_2$, $Mg(NO_3)_2$, $Co(NO_3)_2$, and $NaNO_3$ in separate wells on the plate.

2. Add 2-3 drops of 1 M NH_4OH to each of the wells from step 1. Mix the contents of the well with a clean toothpick.

3. Record your observations.

4. Empty the contents of the spot plate into a large waste beaker and rinse the plate with water.

PART 3: AQUEOUS INORGANIC SALT + AQUEOUS HCl

1. Obtain a clean spot plate. Place four drops each of 0.9 M Na_2CO_3, Na_2SO_4 and $NaNO_3$ in separate wells on the plate.

2. Add 2-3 drops of 6 M HCl to each of the wells from step 1. Mix the contents of the well with a clean toothpick.

3. Record your observations.

4. Empty the contents of the spot plate into a large waste beaker and rinse the plate with water.

PART 4: SOLID INORGANIC SALT OR METAL + WATER OR AQUEOUS HCl

1. Obtain a clean spot plate. Place a small amount of solid $CaCO_3$, Zn, and $Mg(OH)_2$ in separate wells on the plate.

2. Add 6 drops of deionized water to each of the wells from step 1. Mix the contents of the well with a clean toothpick.

3. Record your observations.

4. Empty the contents of the spot plate into a large waste beaker and rinse the plate with water.

5. Obtain a clean spot plate. Place a small amount of solid $CaCO_3$, Zn, and $Mg(OH)_2$ in separate wells on the plate.

6. Add 5-6 drops of 6 M HCl to each of the wells from step 5. Mix the contents of the well with a clean toothpick.

7. Record your observations.

8. Empty the contents of the spot plate into a large waste beaker and rinse the plate with water.

Data Table

PART 1: AQUEOUS SOLUTIONS OF INORGANIC SALT 1 + INORGANIC SALT 2

Solution Used (4 drops)	Solution Used (2 to 3 drops)			
	(B1) Sodium carbonate **0.9M Na_2CO_3**	**(B2)** Sodium sulfate **0.9M Na_2SO_4**	**(B3)** Sodium hydroxide **1 M NaOH**	**(B4)** Sodium chloride **0.9M NaCl**
(A1) Barium nitrate **0.9M $Ba(NO_3)_2$**				
(A2) Calcium nitrate **0.9M $Ca(NO_3)_2$**				
(A3) Magnesium nitrate **0.9M $Mg(NO_3)_2$**				
(A4) Cobalt nitrate **0.9M $Co(NO_3)_2$**				
(A5) Cupric nitrate **0.9M $Cu(NO_3)_2$**				
(A6) Aluminum nitrate **0.9M $Al(NO_3)_3$**				
(A7) Ammonium nitrate **0.9M NH_4NO_3**				

PART 2: AQUEOUS INORGANIC SALT + AQUEOUS NH_3

Solution Used (2 to 3 drops)	Solution Used (4 drops)			
	(A1) Barium nitrate **0.9M $Ba(NO_3)_2$**	**(A3)** Magnesium nitrate **0.9M $Mg(NO_3)_2$**	**(A4)** Cobalt nitrate **0.9M $Co(NO_3)_2$**	**(A8)** Sodium nitrate **0.9M $NaNO_3$**
(B5) Ammonium hydroxide **1M NH_4OH**				

PART 3: AQUEOUS INORGANIC SALT + AQUEOUS HCl

Solution Used (2 to 3 drops)	Solution Used (4 drops)		
	(B1) Sodium carbonate **0.9M Na_2CO_3**	**(B2)** Sodium sulfate **0.9M Na_2SO_4**	**(A8)** Sodium nitrate **0.9M $NaNO_3$**
(B6) Hydrochloric acid **6M HCl**			

PART 4: SOLID INORGANIC SALT OR METAL + WATER OR AQUEOUS HCl

Add	Amount of solid needed is about the size of this dot **O**		
	Calcium carbonate	Zinc	Magnesium hydroxide
Deionized water (6 drops)			
(B6) Hydrochloric acid **6M HCl** (5 to 6 drops)			

Data Analysis

PART 1: AQUEOUS SOLUTIONS OF INORGANIC SALT 1 + INORGANIC SALT 2

For each instance where a reaction was observed, write the molecular, total ionic, and net ionic equation. Use the back of the page or your laboratory notebook to complete if additional space is needed for this section.

Example: A1 + B2
Molecular: $Ba(NO_3)_{2(aq)} + Na_2SO_{4(aq)} \rightarrow 2NaNO_{3(aq)} + BaSO_{4(s)}$
Total Ionic: $Ba^{2+}_{(aq)} + 2NO_3^-{}_{(aq)} + 2Na^+_{(aq)} + SO_4^{2-}{}_{(aq)} \rightarrow 2Na^+_{(aq)} + 2NO_3^-{}_{(aq)} + BaSO_{4(s)}$
Net Ionic: $Ba^{2+}_{(aq)} + SO_4^{2-}{}_{(aq)} \rightarrow BaSO_{4(s)}$

PART 2: AQUEOUS INORGANIC SALT + AQUEOUS NH_3

For each instance where a reaction was observed, write the molecular, total ionic, and net ionic equation.

PART 3: AQUEOUS INORGANIC SALT + AQUEOUS HCl

For each instance where a reaction was observed, write the molecular, total ionic, and net ionic equation.

PART 4: SOLID INORGANIC SALT OR METAL + WATER OR AQUEOUS HCL

For each instance where a reaction was observed, write the molecular, total ionic, and net ionic equation.

Final Review

1. Using the results from Part 1, fill in the following solubility chart. Place an "*S*" (soluble) in the grid for combinations of ions that do not precipitate, and an "*I*" (insoluble) for those that do. The first row is already completed as an example.

Cations	**Anions**				
	CO_3^{2-}	**SO_4^{2-}**	**OH^-**	**Cl^-**	**$C_2H_3O_2^-$**
Group 1A	S	S	S	S	S
Ba^{2+}					S
Ca^{2+}					S
Mg^{2+}					S
Ag^+	I	I	I	I	S
Co^{2+}					S
Cu^{2+}					S
Al^{3+}					S
NH_4^+					S

2. Referring to the chart you have completed, answer the following questions: (Use the information in your chart only, do not use any other source, including your textbook!)

   a. Are ionic compounds containing the ammonium ion generally soluble or insoluble? Are there any exceptions?

   b. Are ionic compounds containing the carbonate ion generally soluble or insoluble? Are there any exceptions?

c. Are ionic compounds containing the sulfate ion generally soluble or insoluble? Are there any exceptions?

d. Are ionic compounds containing the hydroxide ion generally soluble or insoluble? Are there any exceptions?

e. Are ionic compounds containing the chloride ion generally soluble or insoluble? Are there any exceptions?

f. Are ionic compounds containing the acetate ion generally soluble or insoluble? Are there any exceptions?

3. Compare your results with the solubility rules from the textbook. Are the two in agreement?

4. Based on your results from Part 2, does a precipitate form when aqueous ammonia is added to
   a. an aqueous solution of $NaNO_3$?

   b. an aqueous solution of $Mg(NO_3)_2$?

   c. Why do solutions of these two compounds, $NaNO_3$ and $Mg(NO_3)_2$, behave differently when aqueous ammonia is added?

5. Based on your results from Part 3, do nitrates and sulfates react with acids in a gas forming reaction similar to the way carbonates and hydrogen carbonates react? What observations form the basis for your answer to this question?

6. A compound is known to be Na_2CO_3, Na_2SO_4, NaOH, NaCl, $NaC_2H_3O_2$ or $NaNO_3$. When a barium nitrate solution is added to a solution containing the unknown a white precipitate forms. No precipitate is observed when a magnesium nitrate solution is added to a solution containing the unknown. What is the identity of the unknown compound? Clearly and completely explain your reasoning.